



Turbine Engine Technology Support Program and Ceramic Turbine Engine Demonstration Program. These programs are among many related DOE-sponsored efforts that support the core hybrid teams.

## **Compression ignition engine**

Progress continues to be made in advancing the Compression ignition, direct-injection (CIDI) engine, (more commonly called the diesel engine), which has the highest thermal efficiency of any internal combustion engine. Challenges include a lower specific power than the gasoline engine; significant particulate matter and nitrogen oxides in the exhaust; and the noise, vibration, and smell of the engine, which are generally considered as negatives.

Recent advancements in European high-speed automotive diesel engines that address some of these shortcomings have made them nearly ideal candidates for HEV applications. These advancements include high-pressure direct fuel injection, low NOx catalysts, and sophisticated electronic controls. With a thermal efficiency greater than 40% and well-understood maintenance, reliability, manufacturing, and operating characteristics, the high-speed CIDI engine shows great promise as a near-term hybrid HPU.

## **Stirling engine**

The Stirling cycle external combustion engine has certain characteristics that make it a potential candidate for the HEV. Among these are high thermal efficiency, potential for low emissions, and low noise. The principal disadvantage is low power density due to external combustion and large heat rejection requirements. In addition, there is little experience with Stirling engines in automotive applications; most working knowledge of the technology is in aerospace and cryogenic cooling applications.

Previous work sponsored by DOE has shown that the transient response of the engine is poorly matched to conventional drivetrain vehicle demands. For a series hybrid, this constraint would be mitigated; thus the engine is potentially attractive in some HEV applications.

## **Fuel cells**

Fuel cells generate electricity through an electrochemical reaction combining hydrogen with ambient air. They can utilize pure hydrogen or any onboard fossil fuel that is "reformed" to produce a hydrogen-rich gas. Methanol is a common fuel choice.

For the most part, the fuel cell's only emission is water vapor, making it the potentially cleanest HPU alternative, as well as efficient, quiet, and reliable. Fuel cells are predicted to demonstrate energy conversion efficiencies greater than 50%, very high in comparison to the 20-25% efficiency of standard gasoline engines.

The choice of fuel for a fuel cell-powered HEV has important implications for required infrastructure, system accessories, efficiency, cost, and design. Although its viability has been well proven in the space program, as well as in prototype vehicles developed by DOE and industry partners, very high capital costs, large size, long start-up times, and immature technologies place it as a longer-term enabling technology for a commercializable HEV.

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